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Nitrogen Movement with Furrow Irrigation Method and Fertilizer Band Placement

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ABSTRACT

Alternate-furrow irrigation has been proposed as a method to increase irrigation water use efficiency, increase capture and storage of rainfall during the irrigation season, and decrease deep percolation of water. We hypothesized that less fertilizer leaching would occur if the applied fertilizer were spatially separated from the irrigation water in a furrow irrigation system. A study was conducted on a Fort Collins loam (fine-loamy, mixed, superactive, mesic Aridic Haplustalf) in 1994 and 1995 near Fort Collins, CO. Nitrogen uptake by corn (*Zea mays* L.) and N leaching were determined with alternate-furrow and every-furrow irrigation water applications, each with fertilizer bands of ^{15}N-enriched $(NH_4)_2SO_4$ placed either in the row or in the furrow. In 1994 fertilizer N leached to ≈1 m for the every-furrow irrigation with fertilizer placed in the irrigated furrow, but to 0.5 m or less for the other treatments. In 1995 the fertilizer leaching was similar among the treatments because of less irrigation and more rainfall during the growing season. There were no statistically significant differences for irrigation water placement effects on plant biomass or total N uptake, indicating that alternate-furrow irrigation is not detrimental to crop production compared with every-furrow irrigation for similar applications of water. This study showed that placing fertilizer in the nonirrigated furrow of an alternate-furrow irrigation system or placing fertilizer in the row with either alternate- or every-furrow irrigation has the potential to decrease fertilizer leaching without reducing crop productivity.

Furrow irrigation is commonly used in arid, semiarid, and subhumid regions to apply water to row crops. Deep percolation losses of water generally occur with furrow irrigation because, to apply sufficient water to replenish the root zone of the soil farthest from the source, overirrigation occurs near the source. Overirrigation can lead to greater leaching of fertilizers and pesticides to groundwater. Furrow-irrigated corn has been identified as a major contributor to groundwater NO_3^- pollution (Wylie et al., 1994). Artiola (1991) measured as much as 40% of the available NO_3–N lost from the root zone from one 300-mm irrigation on a clay loam. Most of the NO_3^- losses occurred on the two-thirds of the field closest to the irrigation source and no significant NO_3^- losses were measured on the third of the field farthest from the water source.

Water is usually applied by producers to each furrow in the field but some researchers (Fischbach and Mulliner, 1974; Musick and Dusek, 1974; Crabtree et al., 1985) have proposed irrigating alternate furrows instead of every furrow in a field to increase the chance for rainfall storage and increase water use efficiency. Small yield losses were recorded for sugarbeet (*Beta vulgaris* ssp. *vulgaris*), sorghum [*Sorghum bicolor* (L.) Moench], and potato (*Solanum tuberosum* L.) by Musick and Dusek (1974) and for soybean [*Glycine max* (L.) Merr.] by Crabtree et al. (1985) for the alternate-furrow irrigation system when compared with every-furrow irrigation, but irrigation water use decreased by 30 to 50%. The greatest yield losses for alternate-furrow irrigation were at locations farthest from the water source, which indicates that inadequate water was being applied. Fischbach and Mulliner (1974) did not observe lower corn yields with alternate-furrow irrigation than with every-furrow irrigation even though irrigation water application was 30% less with alternate-furrow irrigation.

A method to limit chemical movement to groundwater is to isolate the chemical from the percolating water. Kemper et al. (1975) showed that leaching of salt out of the root zone could be reduced in a furrow irrigation system by placing the band of salt in the ridge at a level equal to or higher than the water level in the furrow. They measured no salt leaving the root zone with a band of salt placed at or above the level of water in the furrow, even with a loamy sand soil and 1000 mm of overirrigation. When the salt was broadcast on a flat surface with flood irrigation or placed in a band below the level of water in the furrow with a ridge–furrow surface, nearly all the salt was leached from the soil after 1000 mm of overirrigation. Hamlett et al. (1986) showed reduced NO_3^- and Br^- leaching from a band of fertilizer placed under the ridge in a ridge-tillage system compared with a flat surface for equal precipitation. Their analysis of water movement suggested that the ridge helped isolate NO_3^- and Br^- from leaching, even though more downward movement of water occurred in the ridge system than the flat system. Benjamin et al. (1994) showed the potential for less leaching of a salt when it was placed in the ridge than if placed in the furrow. They also showed less leaching when the chemical was placed in the nonirrigated furrow than if placed in the irrigated furrow. The study concluded that if the salt were a fertilizer, there was sufficient wetting of the nonirrigated furrow that the fertilizer would be available for plant uptake.

The objective of this study was to determine whether N leaching would be reduced if the N fertilizer were spatially isolated from the irrigation water by placing the fertilizer either in the row with alternate- and every-furrow irrigation or in the nonirrigated furrow of an alternate-furrow irrigation system.

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Abbreviations: ANOVA, analysis of variance; ET, evapotranspiration.

MATERIALS AND METHODS

The study was conducted at the Agricultural Research, Development, and Education Center (ARDEC) near Fort Collins, CO, on a Fort Collins loam in 1994 and 1995. The experiment had a split-plot design with four replications. Ridges approximately 0.1 m higher than the corresponding furrow were built with a cultivator in the spring before planting and fertilizer application. The main plots, 21 m long and 4.5 m (six rows) wide, consisted of irrigation water placed either in every furrow or in alternate furrows (Fig. 1). Because of the relatively short plot lengths, and also to have precise control of the volume of water applied to each plot, we simulated furrow irrigation by modifying a low-energy, precision application (LEPA) linear-move irrigation system. The drop nozzles on the LEPA system were fitted with socks to apply the water in the center of the furrows. Small furrow dikes were constructed in the furrows so that the water ponded in the furrow while the linear-move irrigator traveled the length of the plot. Water was applied approximately weekly at a rate equal to 100% of estimated evapotranspiration. The equivalent volume of water was placed either in every furrow or in alternate furrows, as appropriate, so that the total amount of water was the same for each treatment. Water was placed in the wheel-tracked furrow of the alternate-furrow irrigation treatment.

Two subplots, each 1.5 m long and 1.5 m (two rows) wide, were placed within each irrigation main plot for furrow placement and row placement applications of N fertilizer (Fig. 1). A small slot, approximately 0.1 m deep, was dug by hand near the plant row for row placement and in the center of the furrow for furrow placement in both every-furrow and alternate-furrow irrigation treatments. Nitrogen-15-enriched $(NH_4)_2SO_4$ (5.0 atom % ^{15}N) fertilizer was dissolved in water and applied with a hand sprayer to the bottom of the trench at a rate of 1.0 L for each 1.5-m length of row at a N rate of 145 kg ha^{-1}. Fertilizer was applied shortly after planting (Fig. 2). The delay of fertilizer application in 1995 compared with 1994 was caused by unusually rainy conditions after planting.

Neutron probe access tubes (1.8 m long) were installed in the furrows and in the row between the furrows just outside of each fertilizer plot (Fig. 1). Water contents were measured at 30-cm intervals from 0.15 to 1.65 m before each irrigation and 48 h after each irrigation. Undisturbed soil cores (100-mm diam.) were collected at 75-mm intervals to a depth of 1 m from each replication to determine bulk density and water retention characteristics of the soil.

Plots were planted to corn on 3 May 1994 and 11 May 1995 with a population of approximately 81 500 plants ha^{-1} and thinned to 71 600 plants ha^{-1} after emergence. In 1994 plant samples for biomass and ^{15}N analysis were collected at the R6 (Ritchie and Hanway, 1982) development stage on 19 September. In 1995, a killing frost occurred before physiological maturity at about R5, so plant and soil samples were collected at that time. Four plants were collected from each fertilizer plot. This number of plants is commonly used with ^{15}N-enriched microplots (Blaylock et al., 1990) because of the small plot size. Sampling more plants in the microplot would have increased the chance that the plants would get more of their N from outside the plot. The plants were weighed for biomass determination and analyzed for total N and for atom % ^{15}N on a continuous-flow combustion analyzer coupled with an isotope-ratio mass spectrometer (Marshall and Whitehead, 1985). In 1994, soil samples were collected after plant harvest in the east furrow, the plant row, and the west furrow at 0.15-m increments to a depth of 1.5 m with a 50-mm-diam. soil probe. In 1995, however, soil samples were collected at the same depths from the east furrow, midway between the east furrow and the row (east shoulder position), the plant row, midway between the row and the west furrow (west shoulder position), and the west furrow.

Fertilizer N (fertN) was determined from the total N in the plant or soil sample (totN) and by the change of atom % ^{15}N in the sample (sap^{15}N) due to application of the ^{15}N-enriched fertilizer by

$$\text{fertN} = \text{totN}(\text{sap}^{15}\text{N} - \text{nap}^{15}\text{N})/(\text{aap}^{15}\text{N} - \text{nap}^{15}\text{N}) \quad [1]$$

where aap^{15}N is the atom % ^{15}N in the fertilizer (5.0%). Check samples of plant and soil collected outside the fertilizer plots had a background atom % ^{15}N (nap^{15}N) of 0.372%.

Fertilizer N at each sampling depth was calculated by summing the positional fertilizer N in the soil across the row by

$$N_{\text{layer}} = \Sigma wd[\text{fertN}]\rho_b \quad [2]$$

where [fertN] is the fertilizer N concentration for the sample from Eq. [1], w is the width of the row attributed to the sample, d is the depth increment for the sample, and ρ_b is the bulk density at that position.

An analysis of variance (ANOVA) was used to determine treatment differences on plant biomass, NO_3^- and ^{15}N concentrations in the biomass, total N uptake, and fertilizer N uptake by the plant. The ANOVA was conducted on the summed fertilizer ^{15}N and NO_3^- for each depth and also on the total ^{15}N for the soil profile.

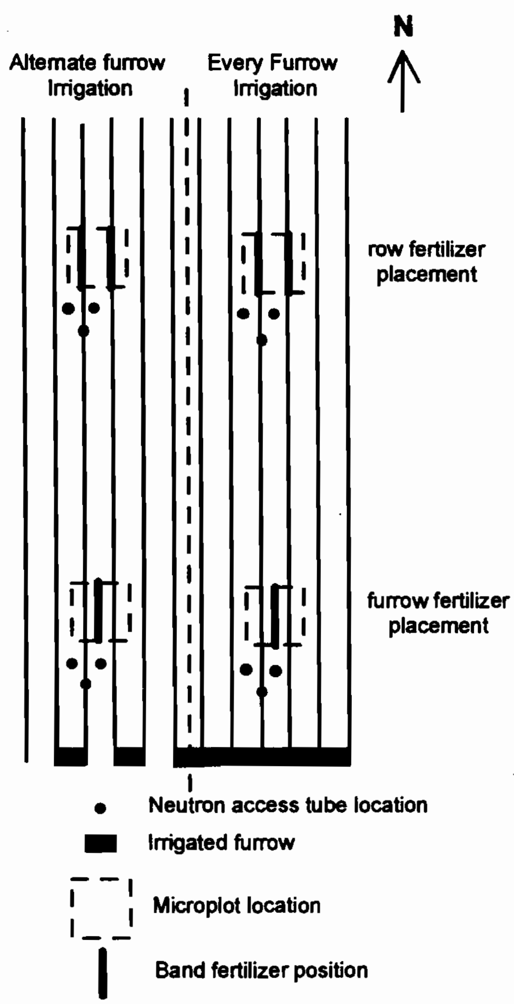

Fig. 1. Schematic of main plot (irrigation placement) showing location of microplots (fertilizer placement) and neutron access tubes.

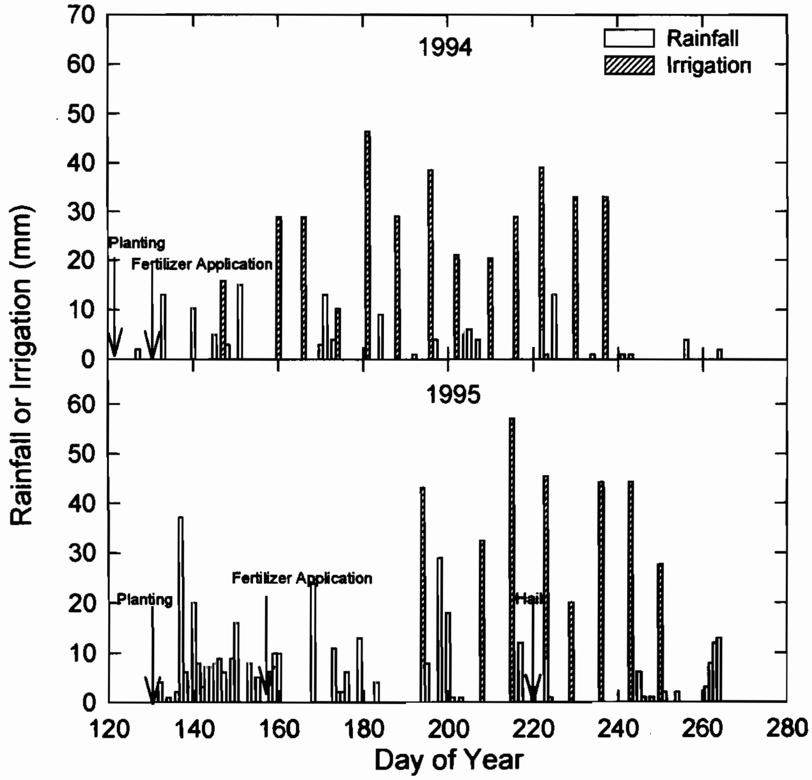

Fig. 2. Rainfall and irrigation timing for 1994 and 1995 at the Agricultural Research, Development, and Edncation Center.

RESULTS AND DISCUSSION

Total growing-season rainfall in 1994 was 127 mm, with 120 mm of rainfall occurring after fertilizer application (Fig. 2). Total irrigation in 1994 was 366 mm and growing-season potential evapotranspiration (ET) was 590 mm. Total growing-season rainfall in 1995 was 384 mm of rainfall, with 225 mm of rainfall occurring after fertilizer application, and total potential ET was 535 mm. Irrigation started ≈45 d later in 1995 than 1994 and the total 1995 irrigation application was 298 mm. Comparing the monthly rainfall amounts for 1994 and 1995 with the 30-yr average showed that 1994 was somewhat drier than normal and 1995, particularly in May and June, was much wetter than normal (Table 1).

Water content measurements in 1994 showed different water environments for the plant between every- and alternate-furrow irrigation systems (Fig. 3). For the alternate-furrow irrigation, the east (nonirrigated) furrow dried out to about a 0.3-m depth and remained dry during the growing season compared with the fluctuating wetter and drier condition of the irrigated west furrow. Very little rewetting occurred in the dry furrow from water moving from the irrigated furrow. At the 0.15-m depth, the water content in the row position was about midway between the water contents of the irrigated and nonirrigated furrow. At the 0.3-m depth and below, the water contents in the row position were very similar to the water contents in the irrigated furrow and wetter than the nonirrigated furrow. These data indicate that wetting occurred in the top 0.3 m from the irrigated furrow into the row, but not across the row into the nonirrigated furrow. Benjamin et al. (1994) predicted rewetting of the nonirrigated furrow from the irrigated furrow in an alternate-furrow irrigation system for a clay loam soil, but their irrigation applications were about 160 mm per irrigation vs. 40 to 50 mm per irrigation in this study. For the every-furrow irrigation, both the furrows and the row had similar water contents that fluctuated with the alternate wetting and drying of irrigation, rainfall, and ET.

Results from the ANOVA on ^{15}N showed a fertilizer placement effect for depths between 0.15 and 0.75 m (Table 2). A significant fertilizer × irrigation interaction was detected for the depth increments between 0.45 and 1.05 m. Less fertilizer leaching occurred with alternate-furrow irrigation and fertilizer placed in the dry furrow or with row placement of fertilizer with either alternate- or every-furrow irrigation compared with every-furrow irrigation and fertilizer placed in an irrigated furrow (Fig. 4). Ninety percent of the fertilizer N was found in the top 0.3 m for the alternate-furrow irrigation with furrow fertilizer placement treatments, whereas 90% of the fertilizer N was contained in the top 1.35 m for the

Table 1. Comparison of 1994 and 1995 monthly rainfall during the growing season with 30-yr (1965–1994) average monthly rainfall at Fort Collins, CO.

	Monthly rainfall			
	May	June	July	August
	mm			
30-yr avg.	68	50	46	33
1994	34	58	29	22
1995	185	136	79	20

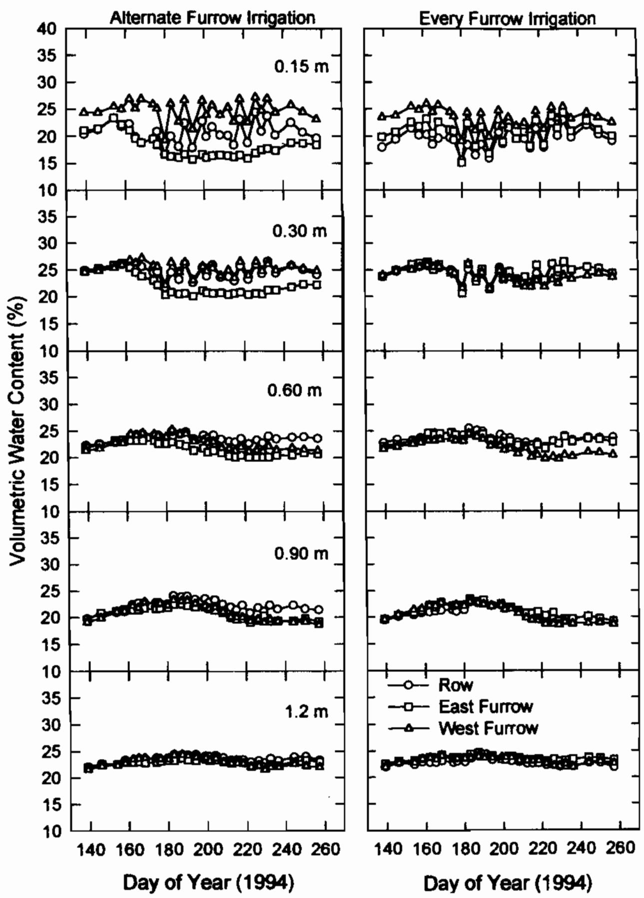

Fig. 3. Water contents by position and depth in 1994. In the alternate-furrow irrigation, the west furrow was irrigated and the east furrow was not irrigated.

every-furrow irrigation with furrow fertilizer placement. Ninety percent of the fertilizer N was contained in the top 0.75 m with row placement and either alternate-furrow or every-furrow irrigation. The NO_3^- distribution at the end of the growing season followed the same

Table 2. Statistical analysis of soil data.

Year	Soil depth	Irrigation	Fertilizer placement	Irrigation × fertilizer placement
	m			
1994	0–0.15	NS	NS	NS
	0.15–0.30	NS	*	NS
	0.30–0.45	NS	*	NS
	0.45–0.60	*	*	*
	0.60–0.75	*	*	*
	0.75–0.90	*	NS	*
	0.90–1.05	NS	NS	*
	1.05–1.20	NS	NS	NS
	1.20–1.35	NS	NS	NS
	1.35–1.50	NS	NS	NS
1995	0–0.15	NS	NS	NS
	0.15–1.30	NS	NS	NS
	0.30–1.45	NS	NS	NS
	0.45–0.60	NS	NS	NS
	0.60–0.75	NS	NS	NS
	0.75–0.90	NS	NS	NS
	0.90–1.05	NS	NS	NS
	1.05–1.20	NS	NS	NS
	1.20–1.35	NS	NS	NS
	1.35–1.50	NS	NS	NS

*** Significant at the 0.05 probability level; NS = not significant.**

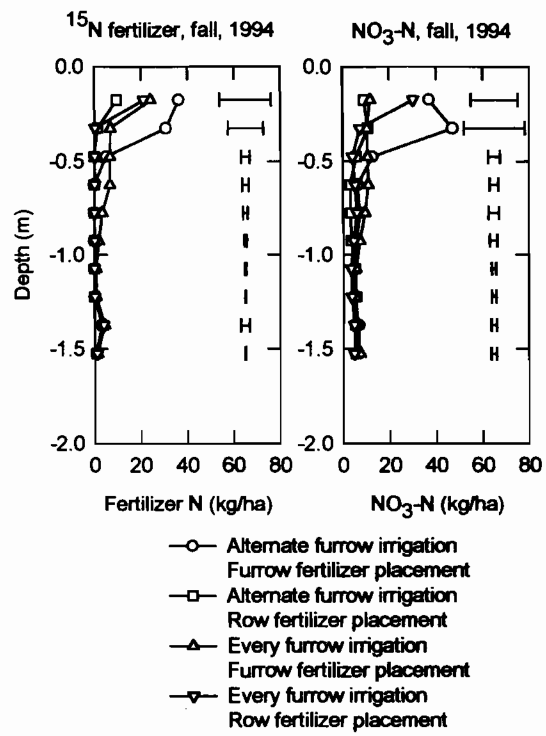

Fig. 4. Fertilizer and NO_3–N distribution in the fall of 1994. The error bars indicate two standard deviations from the mean at each depth.

trends as the fertilizer N distribution. Comparing the fertilizer N distribution with the NO_3^- distribution at the end of the growing season showed that a large amount of the fertilizer N, particularly with the alternate-furrow irrigation and furrow fertilizer placement, was in the NO_3^- form. There was virtually no NH_4^+–N (data not shown) in the soil profile at the end of the growing season.

Positional differences in water contents during the growing season were less in 1995 than in 1994 (Fig. 5). Because of the unusually high amount of spring rainfall, irrigation started ≈45 d later in 1995 than in 1994. The water contents at any depth were similar with the alternate- and every-furrow irrigations. During the irrigation season, there was a tendency for the nonirrigated furrow to dry out, but rainfall then recharged the nonirrigated furrow and equalized the water contents. The soil environment in the nonirrigated furrow for nutrient uptake by the plant would be more favorable in 1995 than in 1994.

The resulting fertilizer N distribution showed fewer differences between irrigation and fertilizer placement treatments in 1995 than in 1994 (Fig. 6). All treatments had >90% of the fertilizer in the top 1 m of soil and the ANOVA analysis showed no significant differences among treatments (Table 3).

No significant treatment effects were observed in either year for plant biomass, total N, or ^{15}N fertilizer concentration in the plant biomass, indicating no detrimental effects from irrigating alternate furrows rather than every furrow (Table 3). In 1994 we accounted for approximately 85 to 90% of the fertilizer applied in the furrow-placement treatments but only about 45% of the

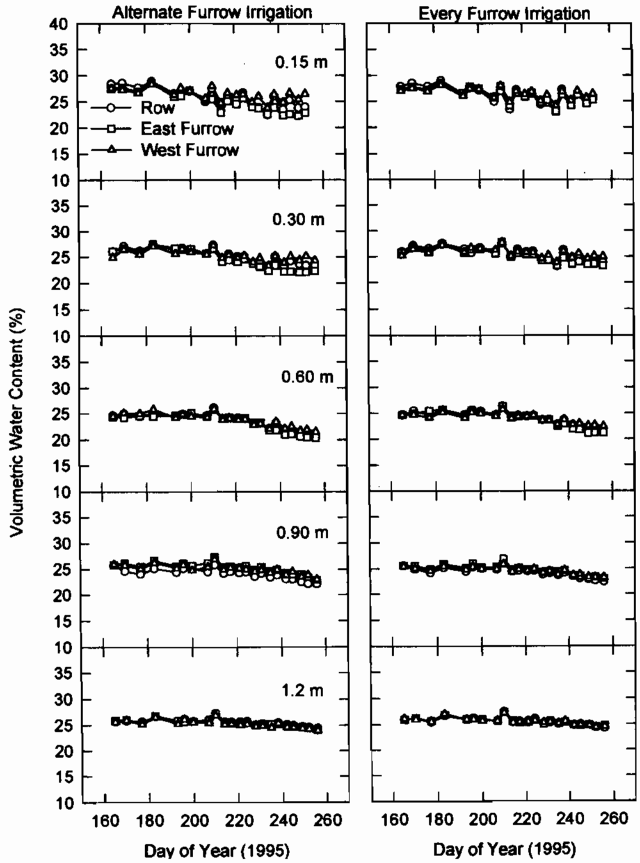

Fig. 5. Water contents by position and depth in 1995. In the alternate-furrow irrigation, the west furrow was irrigated and the east furrow was not irrigated.

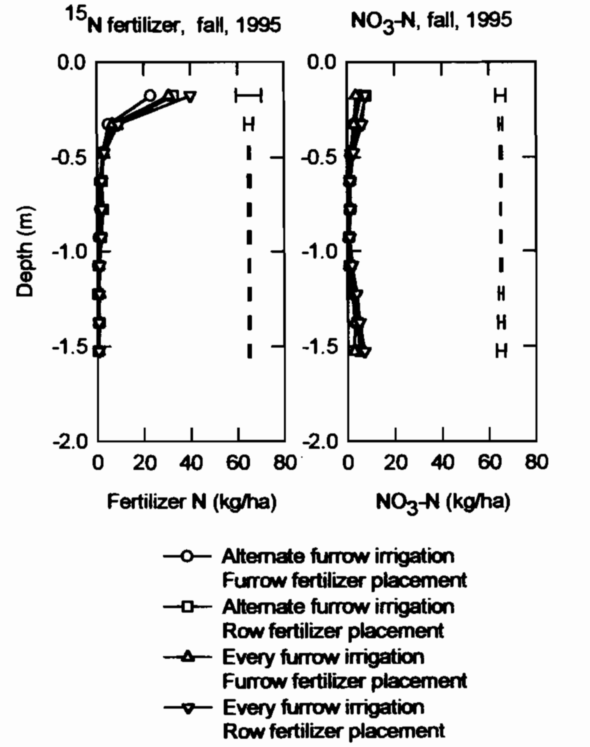

Fig. 6. Fertilizer and NO_3–N distribution in the fall of 1995. The error bars indicate two standard deviations from the mean at each depth.

fertilizer applied in the row-placement treatments. We do not suspect that the reason for the low recovery from row placement was due to excessive leaching or greater denitrification. The greatest leaching and denitrification would probably occur in the irrigated furrow, where we recovered 85 to 90% of the applied N. Leaching and denitrification in the row position should be less than in the irrigated furrow position. We interpreted the low recovery from the row placement treatments as an indication that the sampling scheme used in 1994 was inadequate because of movement of the fertilizer band in the row during the year. The more intensive sampling scheme used in 1995 resulted in a better mass recovery of the fertilizer N, with 80 to 100% of the fertilizer being accounted for in 1995.

CONCLUSIONS

This study showed that placing fertilizer in the nonirrigated furrow of an alternate-furrow irrigation system or placing fertilizer in the row with either alternate- or every-furrow irrigation has the potential to decrease fertilizer leaching without reducing crop production. Greater use of this technique of fertilizer management could significantly reduce groundwater pollution by applied fertilizers and also has the potential to increase N

Table 3. Total plant weight, N concentration in the plant, ^{15}N fertilizer concentration in the plant, total N and ^{15}N fertilizer uptake by plants, residual ^{15}N fertilizer in soil, and mass balance of ^{15}N fertilizer at the end of the growing season in 1994 and 1995.

Year	Irrigation treatment†	Fertilizer placement	Total plant weight	Total N concentration	Fertilizer ^{15}N concentration	Total N uptake	Fertilizer ^{15}N uptake	Fertilizer ^{15}N in soil	Total ^{15}N
			g plant^{-1}	g kg^{-1}		kg ha^{-1}			
1994	al. fur.	furrow	293.5	10.8	2.4	226.6	53.5	75.4a‡	128.9a
	alt. fur.	row	266.7	10.7	2.6	204.5	48.2	13.9b	62.1b
	ev. fur.	furrow	263.6	11.8	3.6	222.4	66.9	54.2a	123.6a
	ev. fur.	row	254.5	10.4	2.4	190.9	43.1	26.5b	69.7b
			NS	NS	NS	NS	NS	*	*
1995	alt. fur.	furrow	173.8	13.2	6.8	165.2	86.3	35.8	122.0
	alt. fur.	row	175.3	12.2	7.0	153.0	87.2	47.0	139.1
	ev. fur.	furrow	169.5	11.7	5.4	143.0	66.4	47.2	113.6
	ev. fur.	row	173.7	12.2	6.8	151.6	85.4	60.4	145.8
			NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level; NS = not significant.
† alt. fur. denotes alternate-furrow irrigation, ev. fur. denotes every-furrow irrigation.
‡ Means followed by different letters are significantly different at $P < 0.05$.

use efficiency by maintaining the fertilizers in the rooting zone of the crop.

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